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INVESTIGATION OF STEVEN IMPACT TEST USING A TRANSPORTATION HOOK PROJECTILE WITH GAUGED EXPERIMENTS AND 3D MODELING

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Abstract. The Steven Impact Test and associated modeling offer valuable practical predictions for evaluating numerous safety scenarios involving low velocity impact of energetic materials by different projectile geometries. One such scenario is the impact of energetic material by a transportation hook during shipping, which offers complexity because of the irregular hook projectile shape. Experiments were performed using gauged Steven Test targets with PBX9404 impacted by a transportation hook projectile to compliment previous non-gauged experiments that established an impact threshold of approximately 69 m/s. Modeling of these experiments was performed with LS-DYNA code using an Ignition and Growth reaction criteria with a friction term. Comparison of the experiment to the model shows reasonable agreement with some details requiring more attention. The experimental results (including carbon resistor gauge records), model calculations, and a discussion of the dominant reaction mechanisms in light of comparisons between experiment and model will be presented.

INTRODUCTION

The Steven Impact Test, which involves a target with High Explosives (HE) that is impacted at increasingly higher velocities with projectiles until you get a “GO” (reaction), has successfully allowed safety evaluation and modeling for accurate predictions. These velocity thresholds (lowest velocity at which you get a “GO”) have been obtained on several different explosives with different projectile head geometries. One practical issue that arose was the safety of explosives in a transportation scenario where the transportation hooks that retain the apparatus could become dislodged and act as projectiles. As a very direct approach, a transportation hook was used as a projectile into a Steven test target.

Steven Impact Test research at Lawrence Livermore National Laboratory [1-6] and a modified version of this test at Los Alamos National Laboratory [7-9] involving both experiments and modeling have greatly increased the fundamental knowledge and practical predictions of impact safety hazards. The dominant microscopic mechanisms that control the initial ignition during compaction of a small volume of the explosive charge have been identified as friction, shear, and strain, however, the relative importance has not yet been determined experimentally. Data has been used to develop a predictive impact ignition reactive flow model based on the Ignition and Growth model for shock initiation and detonation. Further details on the modeling are discussed elsewhere [3-6].

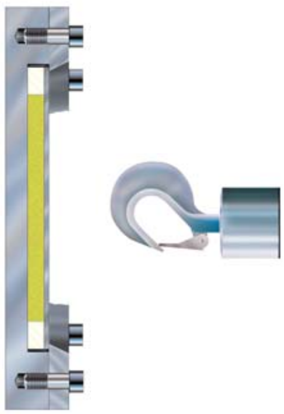


FIGURE 1. Schematic diagram showing Steven Test Target and Transportation Hook Projectile (Projectile #5 in Steven Test Series, 1.6 kg). Note that target shown is the original design and not the updated design with the PMMA outer surround ring used in this work.

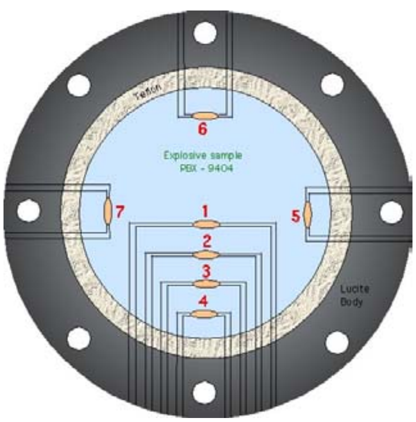


FIGURE 2. Diagram showing the carbon gauge resistor locations in the PBX9404 Steven Test Target.

PROCEDURE

Figure 1 shows a schematic of the experimental geometry of the Steven impact test target. In these tests, a 101 mm diameter smooth bore gas gun accelerates the projectile into the test target consisting of a 110 mm diameter by 12.85 mm thick explosive charge confined by a Teflon surround ring around the circumference, a 3.18 mm thick steel plate on the impact face, a 19.05 mm thick steel plate on the rear surface, and 26.7 mm thick PMMA side outer confinement. The target used in this work with a PMMA (poly-methylmethacrylate) outer confinement is a later version and slightly different than the one shown in Fig.1. The transportation hook projectile was screwed into the 6.01 cm diameter steel body and attached to a polycarbonate sabot. A charge of 20 g H870 primer powder was used to accelerate the entire projectile assembly with plates of various materials and thickness attached to the back of the sabot to vary the total mass, which allowed different projectile velocities to be generated.

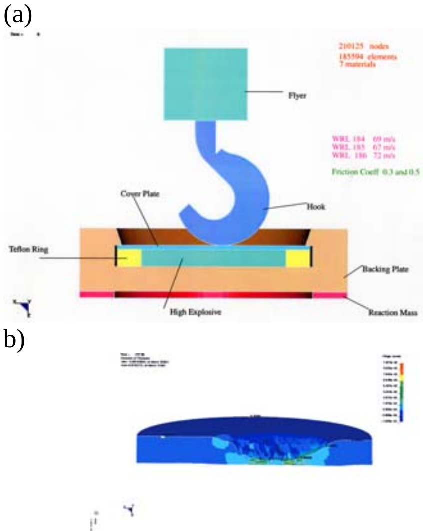
Carbon resistor pressure gauges [10,11] were embedded into the front surface of the explosive sample. These gauges have been used successfully in previous gauged Steven Test experiments [5]. Figure 2 displays the location of the carbon resistor gauges in the PBX 9404 (94% HMX, 3% NC, 3% CEF) [12] explosive sample.

RESULTS/DISCUSSION

A summary of all the hook projectile experiments with PBX9404 is located in Table I including experiment number, projectile velocity, sabot mass, and whether reaction occurred. Experiments WRL203-206 were equipped with carbon resistor gauges. Note that experiment WRL204 showed reaction, whereas the WRL185 did not show reaction at the same 67 m/s velocity. It is assumed that this is due to the presence of the gauges influencing the amount of friction during impact and therefore contributed to the reaction. It was desired to get a low enough velocity to not get a reaction, but only four targets were readily available and because of the system used, precise control over a desired velocity was unobtainable. The reaction threshold is still considered to be 69 m/s, because thresholds are formulated using standard (non-gauged) test results.

Figure 3 displays output gauge records for experiment WRL204 (solid lines). Records for experiments WRL203 and WRL205 showed similar behavior as expected from the similar impact velocity (Table I). From camera images these three experiments can be qualitatively described as “slight GO’s” just based on the size of the reaction fireball. As could be reasonably expected, gauge survivability proved to be a problem with the hook impact. In describing the three similar gauged experiments (WRL203-205), the outer gauges tended to survive longer whereas the gauges close to the hook impact (gauges 1-3) tended to get destroyed early. The peaks in these outer gauges tended to be in the range of 0.3 to 0.4 kbar.

(a)



b)

FIGURE 4. a) Schematic of the material placement in the LS-DYNA code and b) view of the PBX9404 material after running the code.

TABLE I. Summary of all hook projectile experiments. Experiments WRL203-206 had in-situ carbon resistor gauges.

EXPT	VELOCITY	SABOT MASS (kg)	REACTION?
WRL183	37 m/s	3	NO
WRL184	69 m/s	2.4	YES
WRL185	67 m/s	2.7	NO
WRL186	72 m/s	2.5	YES
WRL203	68 m/s	2.7	YES
WRL204	67 m/s	2.5	YES*
WRL205	69 m/s	2.32	YES
WRL206	125 m/s	2.32	YES

*Note that 67 m/s reacted in instrumented experiment but not in the experiment without gauges.

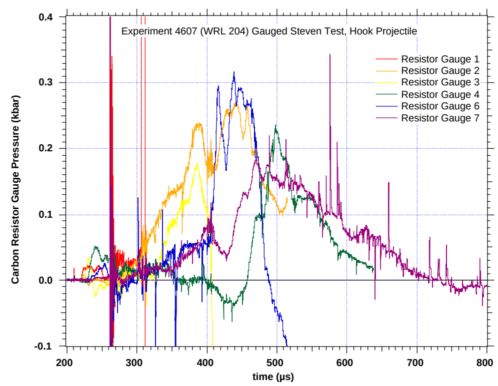


FIGURE 3. Gauge records for experiment WRL204 that are similar to records in experiments WRL203 and WRL205.

As noted in Table 1, a higher velocity experiment (WRL206) was performed at 125 m/s impact with a reaction. The gauge records (not shown) revealed a nice peak on the first gauge up to about 1 kbar, and a peak on outer gauges to about 0.45 kbar before gauge failure occurred. As mentioned above, gauge survivability was a problem, especially at this high velocity.

Modeling of these experiments was performed with LS-DYNA [13] running in 3D with Ignition and Growth reaction criteria and a friction term. As a start, the 67 m/s NOGO test was run. Note that since this was a slight GO in gauged experiment, the direct comparison will not be completely relevant, but it is expected that the results should be comparable. The gauge records from the model output are shown in Fig. 3 as dashed lines. Figure 4(a) and (b) shows the material placement in the LS-DYNA model and contour plot of the PBX9404 well into a run, respectively. It can be seen that at gauge locations the peak pressure is about 1.6 kbar in center to 1 kbar on periphery. These pressures are higher than those measured in the experiment. Understanding these differences is currently in progress, and a strain rate dependent and futher improved material model is in the works. The next step after getting closer agreement with this velocity (67 m/s) is progressing to the 69 m/s case.

SUMMARY AND FUTURE WORK

Experiments were performed using gauged Steven Test targets with PBX9404 impacted by a transportation hook projectile to compliment previous non-gauged experiments. Modeling of these experiments was performed with LS-DYNA code. Comparison of the experiment to the model shows reasonable agreement with more work needed. Future work includes more work to refine the modeling, including incorporation of a strain rate sensitive material model in LS-DYNA. Additional modeling with ALE3D Code for comparison/verification is also desired.

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